

**TIME DOMAIN ELECTROMAGNETIC SURVEYS
FOR ASSISTING IN DETERMINING THE
GROUNDWATER RESOURCES ON
KAWELA PLANTATION PROPERTY
ISLAND OF MOLOKAI**

Project Number 5017

January 2006

Prepared For:
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1.0 INTRODUCTION

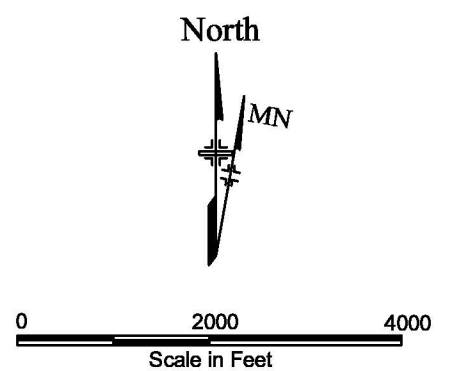
This report contains the results of surface Time Domain Electromagnetic (TDEM) geophysical surveys performed for groundwater resource evaluation at the Kawela Plantation Property located approximately two miles east of the town of Kaunakakai on the Island of Molokai. Blackhawk a Division of ZAPATA ENGINEERING (Blackhawk) conducted the surveys from January 13 through 16, 2006 for Kawela Plantation Homeowners Association (Kawela) of Kaunakakai, Hawaii and Tom Nance Water Resources Engineering (TNWRE) of Honolulu, Hawaii.

TDEM is a geophysical method that determines from the surface the geoelectric section (resistivity layering) of the subsurface. From the geoelectric section, information about geology and water quality can be inferred. This is possible because the electrical resistivity of the earth depends on lithology, porosity, the degree of saturation, and concentration of dissolved solids in the groundwater.

The main objective of the TDEM surveys on Molokai was to explore for possible basal groundwater occurrences at the survey areas. The TDEM surveys were conducted along the approximate 525 ft (160 m) elevation level on Kawela Plantation Properties I, II and III located above the town of Kawela, Hawaii. Figure 1-1 shows the locations of the TDEM soundings taken during this survey on the Kawela Plantation Property along the south coast of Molokai. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths.



- Explanation**
- + ¹ TDEM Loop Location
 - A - - - A' Geoelectric Cross-Section
 - 1
(3.5) Water Well, Static Water Level (Ft.)
 - WT1 Water Tank



North American Datum of 1983 (NAD83).
 Projection and 1,000 meter grid: UTM Zone 4
 10,000 foot ticks: Hawaii Coordinate System
 of 1983 (Zone 2).



**Kawela Plantation
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 Island of Molokai**

**TDEM Loop Location Map
 Kawela Plantation
 Maui County, Island of Molokai**

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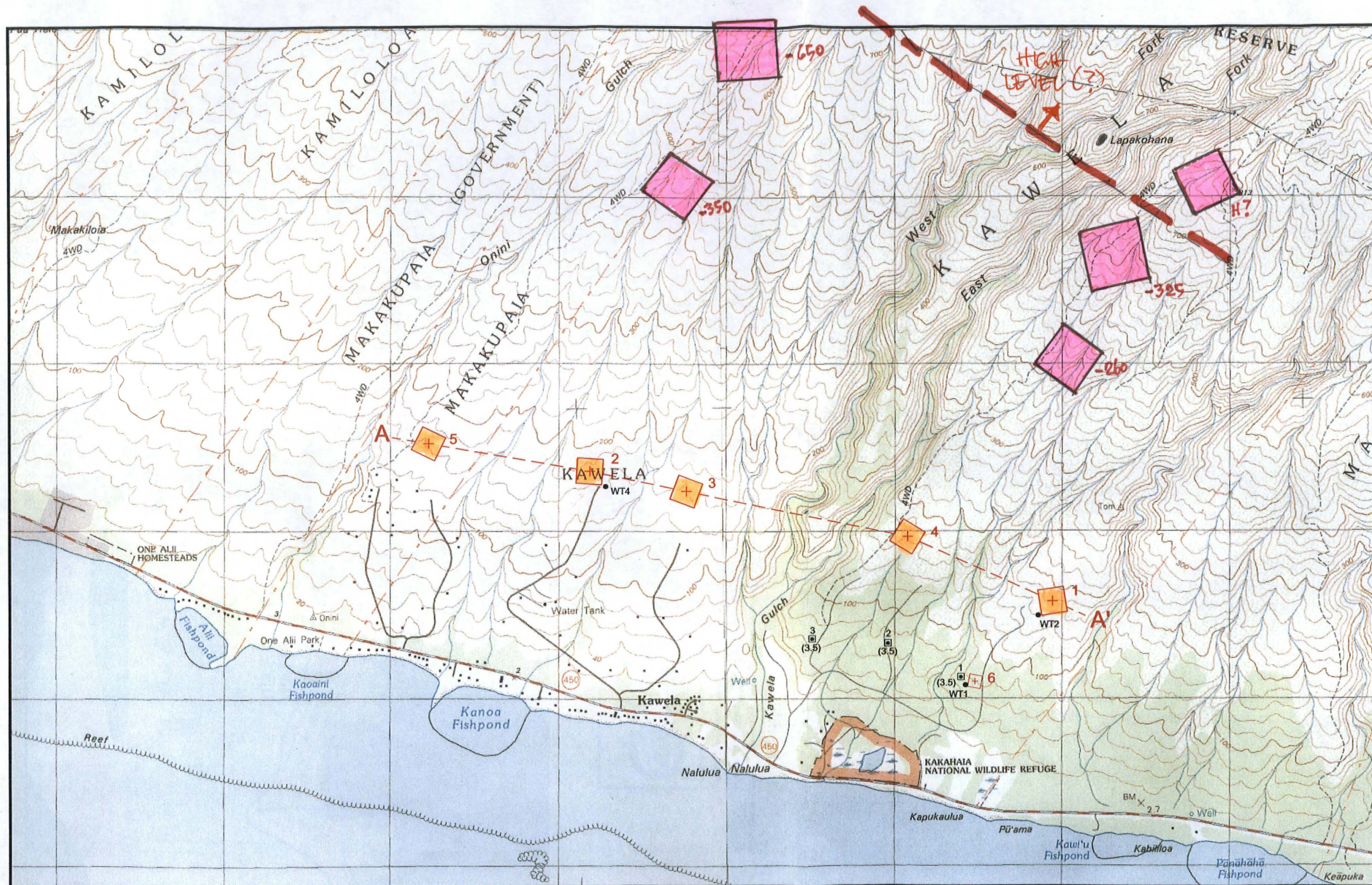
Date:
July 1, 2005

Drawn By:
HJV

Checked By:
RJB

Scale:
1" = 2000'

Figure:
1-1



Explanation

- +¹ TDEM Loop Location
- A — A' Geoelectric Cross-Section
- 1
(3.5) Water Well, Static Water Level (Ft.)
- WT1 Water Tank



0 2000 4000
Scale in Feet

North American Datum of 1983 (NAD83).
Projection and 1,000 meter grid: UTM Zone 4
10,000 foot ticks: Hawaii Coordinate System
of 1983 (Zone 2).

PROPORTION OF THREE



Kawela Plantation
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TDEM Loop Location Map
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Figure:
1-1

2.0 GEOLOGY/HYDROGEOLOGY

Groundwater resources occur on the Hawaiian Islands basically in two modes:

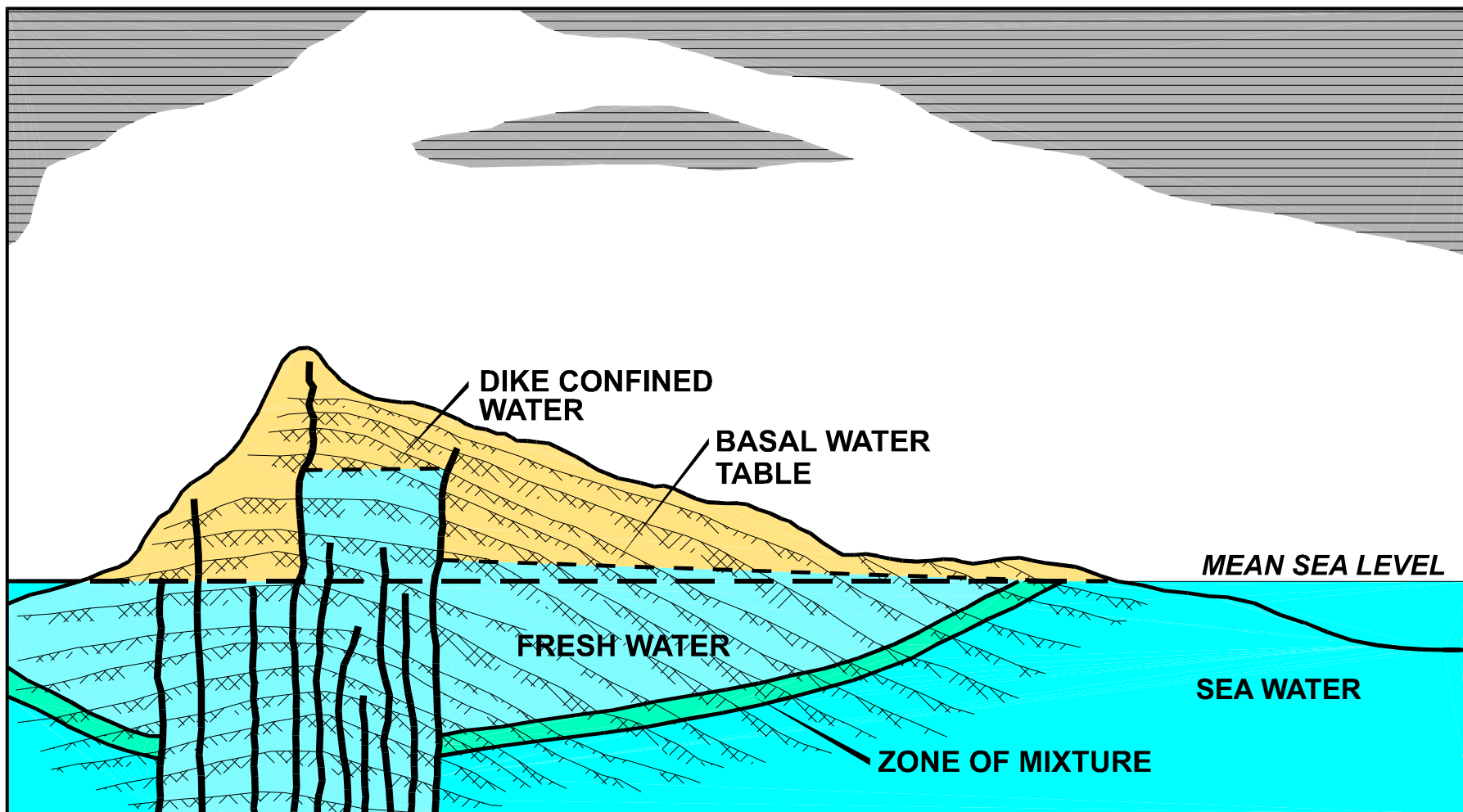
- In a basal mode where a lens of fresh water floats on seawater, and
- In a high-level mode where the fresh groundwater occurrence is controlled by damming structures (i.e. intrusives, dikes, etc).

The basic geologic and hydrologic framework of the Island of Molokai and the two modes of groundwater occurrences are illustrated in Figure 2-1. Fresh groundwater may also occur in areas between these two modes, but production is expected to be highly variable. TDEM surveys previously run on Hawaii have reliably mapped the basal mode groundwater occurrence and the boundary between fresh water in the basal mode and high-level water occurrences. Basal mode groundwater is resting approximately at sea level near the ocean surrounding the Island of Molokai. This is generally due to the fact that the volcanic rocks, which comprise the island, allow rainfall to percolate with little impedance directly downward through the rock mass (reference Figure 2-1). The fresh water floats directly on the seawater encroaching from the ocean. Fresh water flows laterally toward the ocean causing the fresh water lens to be thinner near the ocean. When groundwater is under conditions of static equilibrium, the Ghyben-Herzberg Principle states that for every one foot of fresh water above sea level, approximately 40 ft of fresh water will exist below sea level as shown in Figure 2-2. The transition from fresh water to seawater at depth may be relatively sharp (i.e. occurring over several tens of feet) or more gradual; depending upon hydrologic flux, horizontal to vertical permeability contrast, and other geologic factors. It is assumed, when resolving TDEM data, that seawater saturated volcanics begin at the midpoint of the transition zone.

TDEM surveys are utilized to map the resistivity stratification of the subsurface. From numerous previous TDEM surveys and calibration at well sites, characteristic ranges of subsurface resistivities have been derived for the geologic/hydrologic units shown in Figure 2-3. Some overlap in resistivity occurs between different units, however other factors (such as elevation) can be used to separate the units. Therefore the main geologic/hydrologic units that can be derived from TDEM surveys are:

- Depth to seawater saturated volcanic rocks. This occurs in basal mode situations, and by using the Ghyben-Herzberg Principle; the thickness of the basal fresh water lens can be calculated.
- Weathered volcanic layers (laterites). These lower resistivity units are generally relatively thin (50 ft to 100 ft) layers that occur mainly at or near the ground surface.
- Clay poor and fresh water saturated volcanic rocks. These formations generally exhibit high resistivity values. Note that the extent of fresh water saturation is normally based on geographic and elevation information, and that the fresh water cannot usually be directly detected in the TDEM data.

Groundwater damming structures (i.e. intrusives, dikes) are inferred with TDEM by uncharacteristic sounding curves (distorted by structures), and by soundings that transition between detection of seawater at depth (indicating basal mode groundwater) and soundings that map high resistivities to great depths (indicating possible high-level groundwater) below sea level.



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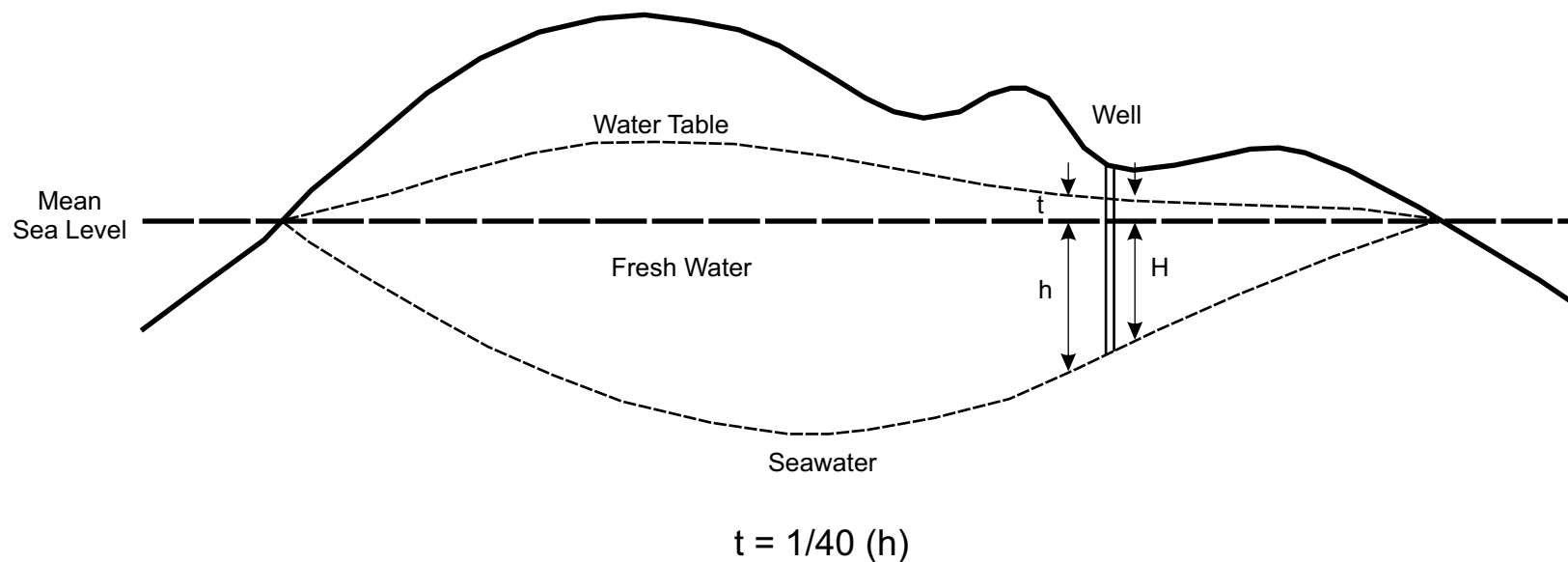
Drawn By:
HJV

Checked By:
RJB

Scale:
No Scale

Figure:
2-1

**Schematic Hydrogeologic
Cross Section
Island of Molokai**



From: Herzberg



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Scale:

No Scale

Figure:

2-2

**Illustration of the
Ghyben-Herzberg Principle**

3.0 DATA ACQUISITION AND LOGISTICS

Blackhawk mobilized a field crew consisting of a project geophysicist and geophysical technician to perform the geophysical surveys. The crew and equipment were mobilized from Golden, Colorado. During the TDEM field surveys on Molokai, Tom Nance Water Resource Engineering (TNWRE) provided project direction and oversight while Kawela personnel provided field site orientation and access (keys to locked gates) to the property. A daily log of field activities during the surveys is presented in Table 3-1.

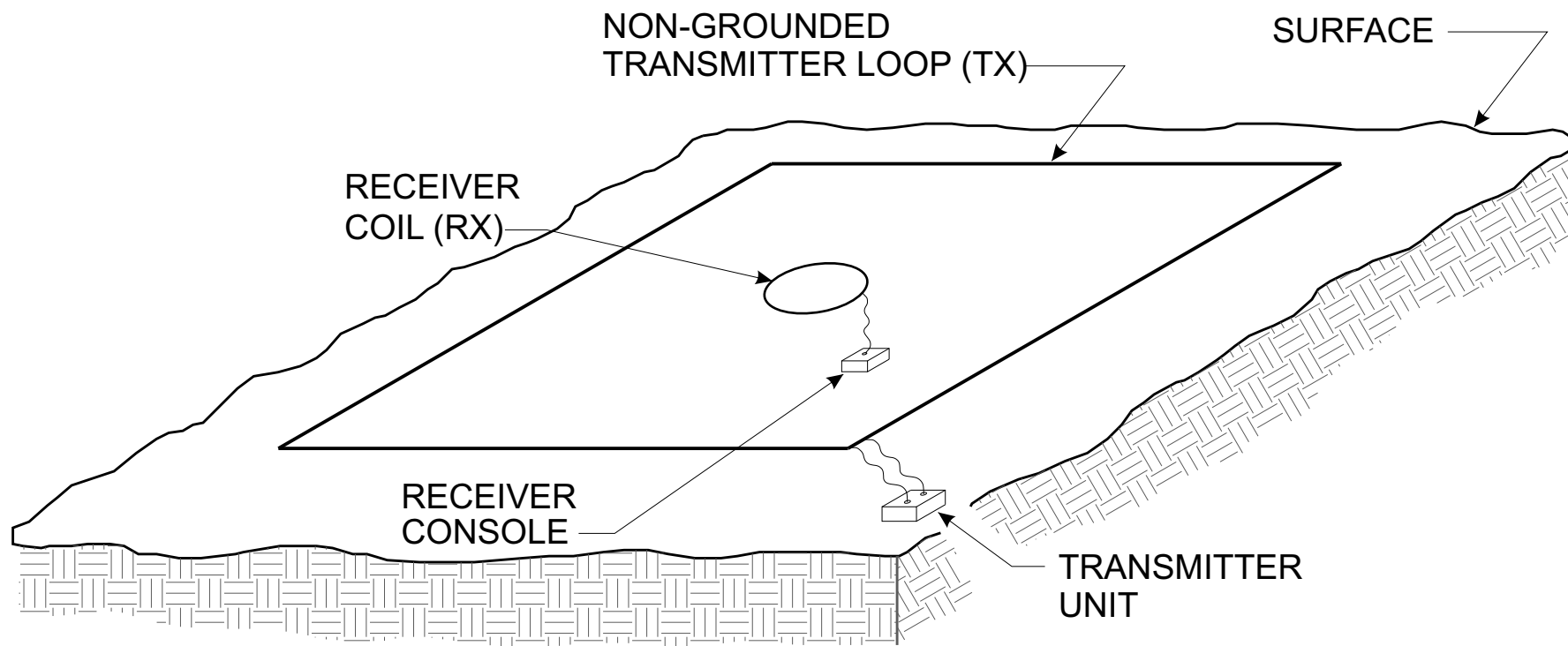
The geophysical equipment utilized for the TDEM surveys was the Geonics EM37 system. The EM37 system consists of both a portable PROTEM digital receiver and a motor-generator powered transmitter. The main purpose of the TDEM measurements is to derive both the vertical and lateral variations in the geoelectric section. To accomplish this, the TDEM measurements were acquired using a central-loop array at each sounding site. Using 12-gauge insulated copper wire laid on the ground surface, as illustrated in Figure 3-1, this formed the square transmitter loops. The dimensions for the transmitter wire loops were 500 ft by 500 ft. A transmitter is placed at a corner in the wire-loop, which drives square-wave current pulses through the wire. A current ranging from 14 to 18 amperes was used in the transmitter loops. The current pulses induce eddy current flow in the subsurface. A receiver coil (1-meter diameter) attached to the PROTEM receiver was positioned in the center of the wire-loop and used to record the decay of the secondary magnetic field due to the eddy currents induced in the subsurface. The effective exploration depth with a 500 ft by 500 ft transmitter wire-loop array is determined to be about 800 ft. Greater exploration depths are reached with larger wire-loops and factors that affect the depth of investigation include ground resistivity (ohm-m) and ambient noise (i.e. 60-cycle power line).

The data acquired at each sounding consisted of measurements utilizing several different receiver gain settings and two transmitter frequencies in order to assure data quality and to obtain data over the longest possible time interval. The data were recorded at base frequencies of 3 Hz and 30 Hz for the TDEM soundings. For data quality control, comparisons of offset measurements (100 ft) were made at designated locations surveyed near the center of each sounding. The data from each sounding were stored in a solid-state memory logger in the PROTEM digital receiver and transferred at the end of each day to a PC for nightly processing. The TDEM data collected at Soundings 1 through 5 were of excellent quality with no measured cultural interference from nearby powerlines and pipelines located at the water tanks and along roadways. The data at Sounding 6 (near Well 1) was determined to be distorted by nearby pipelines and thus was not used in the interpretation. A technical note describing the principles of TDEM with case histories is given in Appendix A.

The transmitter wire-loop corners and centers were registered to the water tanks at Soundings 1 and 2, which are located on the property. Other landmarks, such as road junctions, were also used to locate the corners of the wire-loops on the property map with a hip-chain and compass. In addition, a hand-held Global Positioning System (GPS) with WAAS capability was used to map both the centers and elevations of the soundings and were compared to the topographic map.

A total of six (6) soundings were measured on the Kawela Plantation Property during the three (3) days of fieldwork. The elevations of the TDEM soundings, water tanks and wells are given in Appendix B (Table 3-2).

Table 3-1 Daily Log of Field Activities Kawela Plantation TDEM Survey	
Date (2006)	Activity
January 11	Ship TDEM geophysical equipment from other project in Hawaii to Kaunakakai, Molokai, HI.
January 12	Mobilize Blackhawk field crew from other project in Hawaii to Kaunakakai, Molokai, HI.
January 13	Meet with Kawela Plantation Homeowners Association manager and field representative. Perform reconnaissance of all sounding sites. Unpack TDEM geophysical equipment at Kawela Plantation office and organize into 4WD vehicle. Pickup motor generator from FedEx truck at Hotel Molokai. Prepare and test motor-generator and TDEM equipment.
January 14	Begin geophysical survey. Collect TDEM data on Soundings KP1, KP2 and KP3. Download data to PC and perform preliminary data analysis in hotel. Call TNWRE and discuss results.
January 15	Continue survey. Acquire TDEM data on Soundings KP4 and KP5. Download data to PC and perform preliminary data analysis in hotel. Call TNWRE and discuss results.
January 16	Take data on Sounding KP6 and download data to PC. Pack up TDEM equipment and demobilize from Molokai, HI to Golden, CO.
January 17	Demobilize Blackhawk personnel from Kaunakakai, Molokai, HI to another project in Hawaii.



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January, 2006

Drawn By:

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**Schematic layout of TDEM system
with locations of TX and RX
for Central Loop Array
measurements**

Checked By:

RJB

Scale:

No Scale

Figure:

3-1

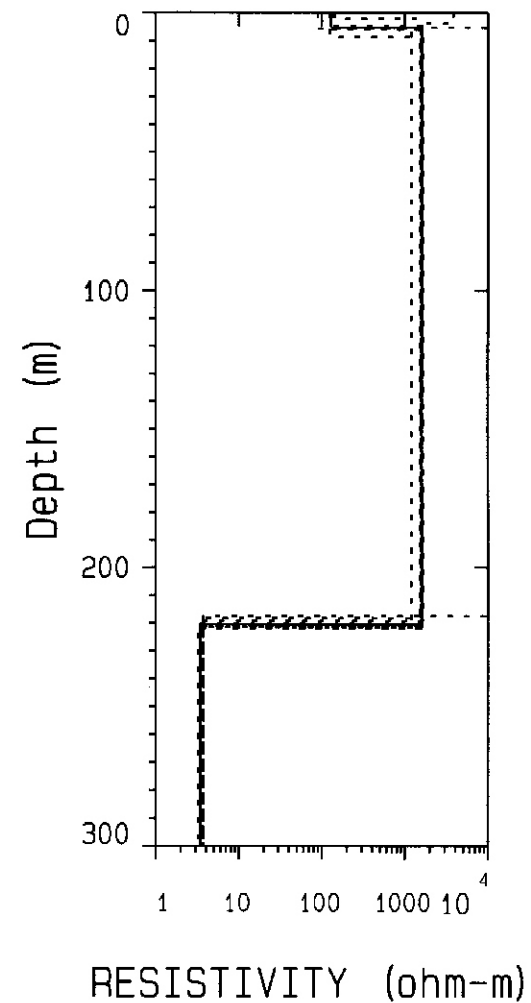
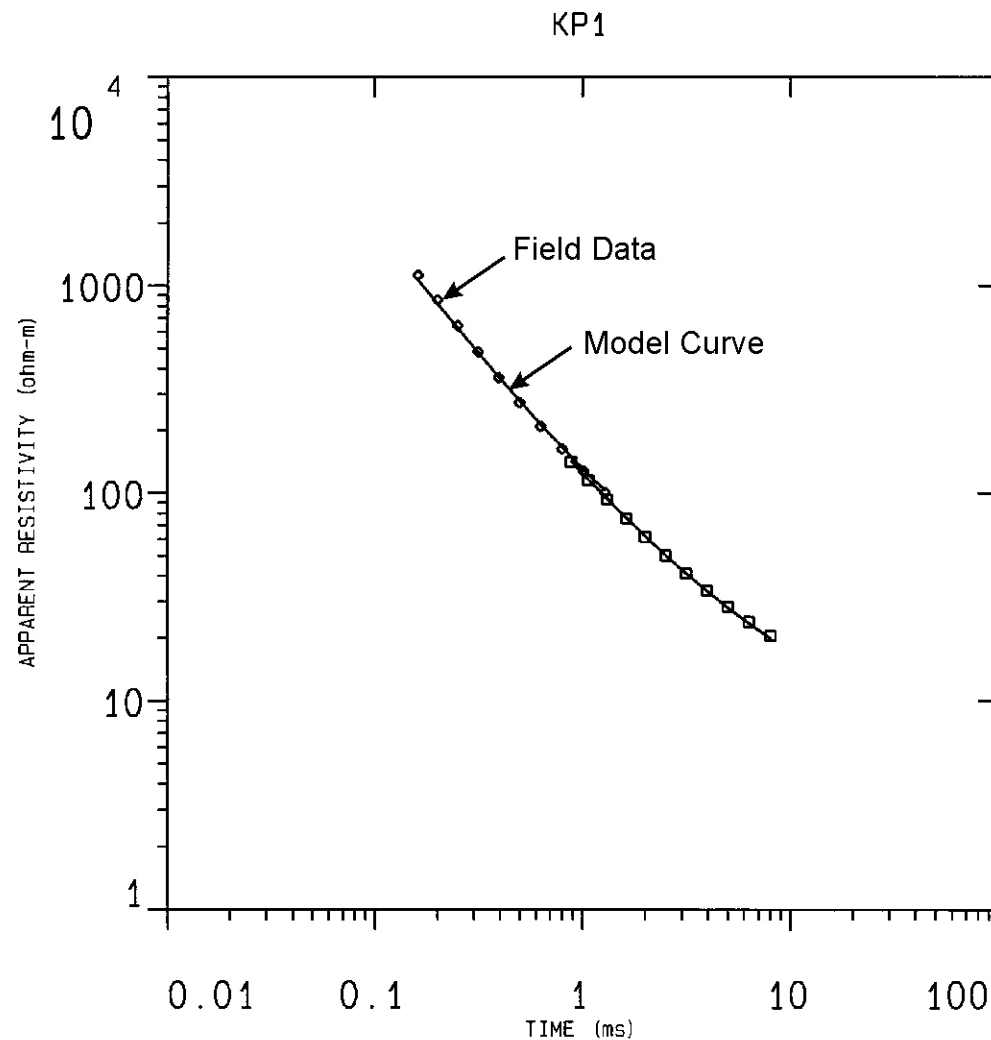
4.0 DATA PROCESSING

The TDEM field data collected at each sounding was transferred nightly from the Geonics PROTEM digital receiver to a PC for editing and processing. Processing of the TDEM data begins with averaging of the electromotive forces recorded at positive and negative receiver polarities. Next, the measurements collected at the two base frequencies (3 and 30 Hz) and different amplifier gains were combined to give one voltage decay curve (transient). The electromotive forces in the various time gates of the decay curves were subsequently entered into the TEMIXXL (Interpex Ltd.) inversion program to obtain a one-dimensional (1-D) geoelectric section that best matches the observed decay curve.

The TEMIXXL inversion program requires an initial model of the geoelectric section measured. The initial model includes the number of layers and the resistivities and thickness for each of the layers. This model is usually derived from general knowledge of the geologic section or from data obtained from drill holes or electric logs. The inversion program is then allowed to adjust the layer thickness and the resistivities, so that the model curve converges to best fit the field data. The inversion program does not change the total number of layers within the model curve, but allows all other parameters to change freely or they can optionally be fixed constant. To determine the influence of the number of layers on the solution, separate inversions with a different number of layers are run. Subsequently, the model with the least number of layers that best fits the field data is used.

An example of the output of the inversion program is shown on Figure 4-1 for Sounding KP1 on the Kawela Plantation Property. This figure shows the measured data points (in terms of apparent resistivity) superimposed on a solid line on the left panel. The solid line represents the computed forward model for the geoelectric section on the right panel. This geoelectric section is the best match obtained by the inversion program. Figure 4-2 shows the tabulated inversion parameters consisting of measured data, computed data for best match solutions and an example of the table of inversion statistics. A three-layer inversion model is shown for Sounding KP1. The model displays a thin (18 ft) moderately resistive (129 ohm-m) surface layer of clay soil (laterite) with a thick (705 ft) resistive (1597 ohm-m) second layer overlying a third conductive (3.4 ohm-m) layer. The depth to the top of the third layer is located at about -137 ft below sea level (bsl) in the section, which is interpreted to be seawater.

The interpreted geoelectric section derived from each TDEM sounding is not unique. The magnitude of each individual layer resistivity and thickness can normally be varied within a limited range with no significant change to the fit of the geoelectric model of the data. This variation is termed equivalence. An equivalence analysis was performed for each TDEM sounding. Figures 4-1 and 4-2 also show the equivalence analysis for Sounding KP1. This sounding is typical of the TDEM data and shows about a +/-5% equivalence in depth determinations and +/-20% in individual layer resistivities. The inversion results for each sounding of this project are given in Appendix B.



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January, 2006

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Scale:
No Scale

Figure:
4-1

**Sounding KP1
Example Inversion Output
Apparent Resistivity Curve**
*Kawela Plantation
Maui Co., Island of Molokai*

DATA SET: KP1

CLIENT: Kawela Plantation
 LOCATION: N.E. of Water Tank 2
 COUNTY: Maui, HI
 PROJECT: Kawela Plantation TDEM Survey
 LOOP SIZE: 152.000 m by 152.000 m
 COIL LOC: 0.000 m (X), 0.000 m (Y)
 SOUNDING COORDINATES: X: 1.0000 N: 1.0000 SLOPE: NONE

DATE: 01-14-06
 SOUNDING: 1
 ELEVATION: 179.00 m
 EQUIPMENT: Geonics PROTEM
 AZIMUTH:
 TIME CONSTANT: NONE

Central Loop Configuration
 Geonics PROTEM System

FITTING ERROR: 3.300 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	CONDUCTANCE (+) (Siemens)
1	129.2	5.48	179.0	587.2
2	1597.3	215.0	173.5	567.2
3	3.46		-41.57	-136.5
				0.0424
				0.134

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER	MINIMUM	BEST	MAXIMUM
RHO			
1	88.598	129.216	3843.884
2	1196.639	1597.307	10348.888
3	3.226	3.469	3.746
THICK			
1	2.171	5.485	8.783
2	212.058	215.085	219.616
DEPTH			
1	2.171	5.485	8.783
2	217.532	220.571	221.913

Equivalence
 Analysis

CURRENT: 18.00 AMPS EM-58 COIL AREA: 100.00 sq m.
 FREQUENCY: 3.00 Hz GAIN: 7 RAMP TIME: 100.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	0.881	171.3	168.1	1.85
2	1.06	144.1	141.6	1.68
3	1.31	118.4	116.3	1.78
4	1.61	95.79	94.78	1.04
5	2.00	76.45	75.53	1.21
6	2.50	59.60	59.17	0.716
7	3.14	45.65	45.41	0.515
8	3.95	34.14	34.21	-0.197
9	4.99	24.95	25.28	-1.29
10	6.31	17.86	18.30	-2.46
11	7.99	12.47	13.00	-4.29

CURRENT: 18.00 AMPS EM-58 COIL AREA: 100.00 sq m.
 FREQUENCY: 30.00 Hz GAIN: 2 RAMP TIME: 100.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
12	0.161	528.8	572.3	-8.21
13	0.200	465.9	496.8	-6.64
14	0.250	410.8	428.3	-4.25
15	0.314	359.2	364.0	-1.32
16	0.395	311.6	308.2	1.09
17	0.499	264.2	255.1	3.45
18	0.631	218.7	211.4	3.33
19	0.799	176.8	169.9	3.88
20	1.01	140.8	137.0	2.72
21	1.28	110.7	107.0	3.38

PARAMETER RESOLUTION MATRIX:
 "F" INDICATES FIXED PARAMETER
 P 1 0.05
 P 2 0.01 0.02
 P 3 -0.02 -0.04 0.87
 T 1 0.09 0.00 0.01 0.19
 T 2 0.00 0.01 0.00 0.02 1.00
 P 1 P 2 P 3 T 1 T 2



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Sounding KP1
 Example of Tabulated Data
 From Inversion

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Scale: No Scale

Figure: 4-2

5.0 INTERPRETATION AND RESULTS

5.1 TDEM SOUNDING DATA

From each TDEM sounding, the geoelectric section of the subsurface is derived. The results of the one-dimensional (1-D) inversion of the individual TDEM soundings can be linked together (layers with similar resistivities) to create a 2-D geoelectric cross-section along a survey transect. For this TDEM survey, six (6) TDEM soundings were collected across the Kawela Plantation Property along the southern coast of Molokai. This data allowed construction of one geoelectric cross-section from west to east as shown on Figure 1-2. The correlations between geoelectric layers and lithologic units established in Figure 2-3 were used to guide the interpretations on this geoelectric cross-section.

5.2 GEOELECTRIC CROSS-SECTION FOR KAWELA PLANTATION TRANSECT A-A'

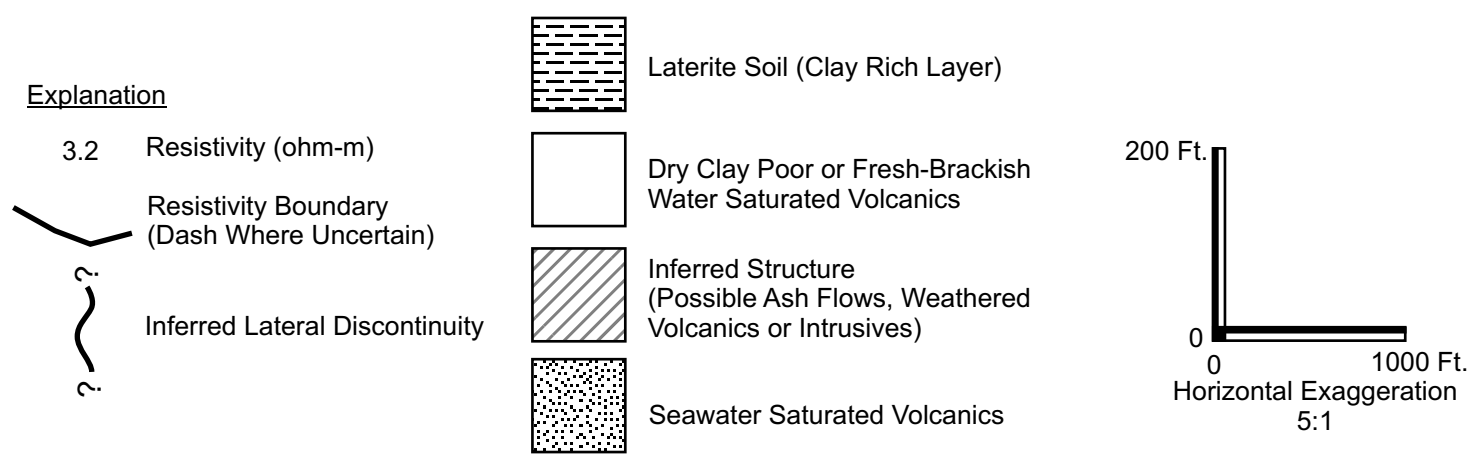
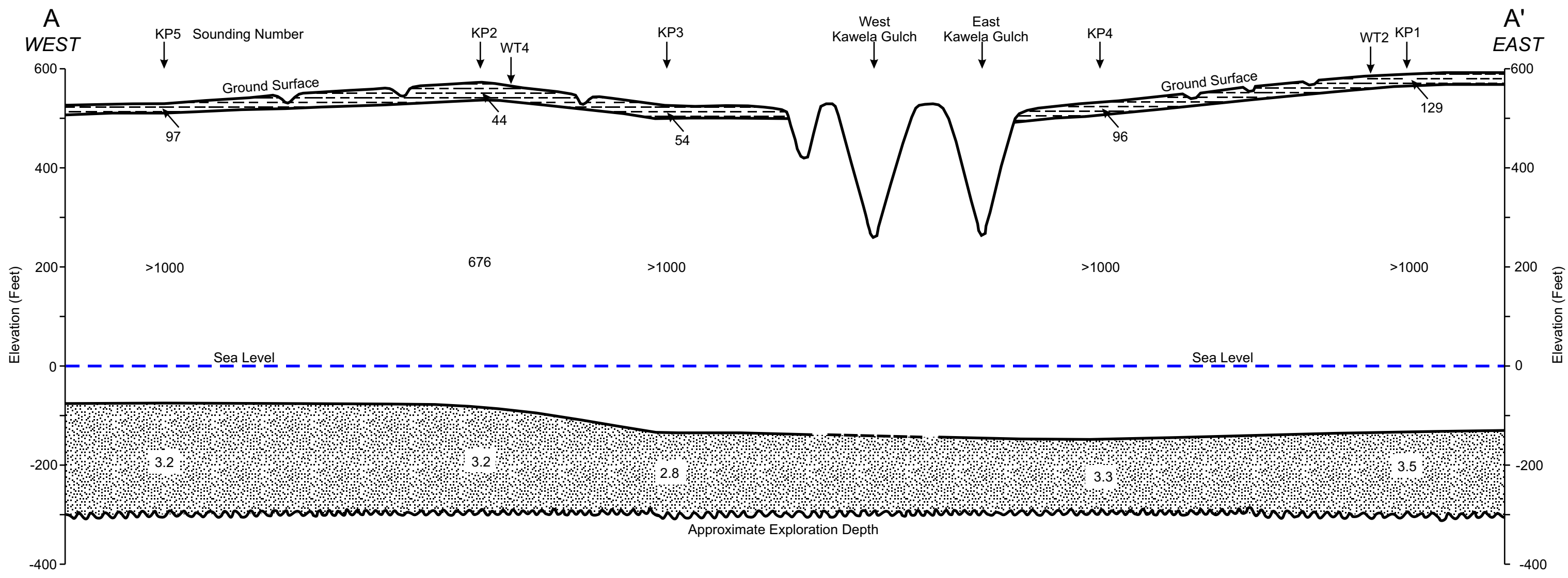
Figure 5-1 shows the layered geoelectric cross-section from the TDEM data taken on the Kawela Plantation Property. The soundings are situated in an approximate west to east trend with the center of Sounding KP5 on the west end, at about 530 ft surface elevation, and Sounding KP1 at about 585 ft elevation on the east end. A three-layer section is interpreted for all five soundings along this transect. The upper layer in the geoelectric cross-section exhibits intermediate to high resistivities ranging from 44 to 129 ohm-m and is interpreted as a relatively thin (15 to 30 ft) laterite soil layer. The second layer in the section exhibits high resistivities that range from 676 to >1000 ohm-m and is interpreted as dry clay poor volcanic formations both above and below sea level. Where the second layer occurs below sea level (bsl) it is expected to be saturated with fresh-brackish basal mode water. The third layer in the section with low resistivities (2.8 to 3.5 ohm-m) is interpreted to represent seawater saturated volcanic layers at depth beneath all soundings. The calculated thickness of the fresh-brackish water lens ranges from about 78 ft beneath Sounding KP5 and up to 145 ft beneath Sounding KP4. The Kawela Water Wells 1, 2 and 3 are located at 235 ft elevation and down slope from Sounding KP4 with each having a reported head of 3.5 ft. The TDEM data shows good comparison for the calculation of head from Sounding KP4 (3.6 ft) from the Ghyben-Herzberg Principle and the water wells, although the sounding is located approximately 2,000 ft lateral distance upslope and at an elevation of 528 ft.


5.3 HYDROGEOLOGIC INTERPRETATIONS

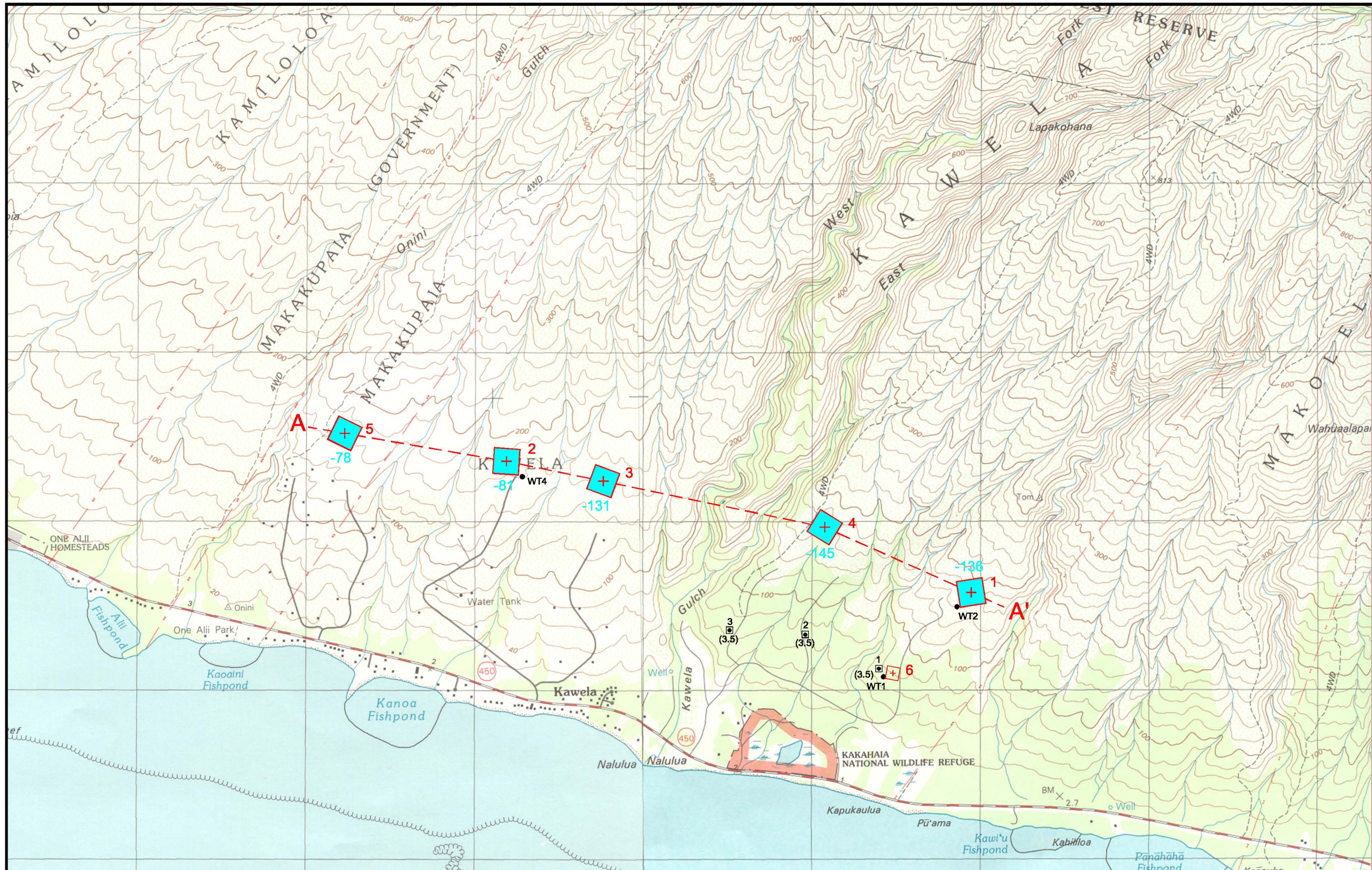
Table 5-1 contains the approximate thickness of the fresh-brackish water lens calculated from the elevation of the seawater interface interpreted from the TDEM soundings taken along the Kawela Plantation Property transect on Molokai. The table includes the value of static water level (head) calculated by using the Ghyben-Herzberg Principle. The TDEM data is further interpreted on the summary map shown in Figure 5-2. On this map all of the TDEM soundings are color coded blue with the elevation of the fresh-brackish/seawater interface listed (i.e. -145 ft) at each sounding.

Table 5-1 Hydrogeologic Information Derived From TDEM Soundings (Values in Feet)				
Sounding Number	Surface Elevation	Elevation of top of the Conductive Layer	Calculated Static Water Level (Head) Using Ghyben-Herzberg Principle	Approximate Thickness of Fresh-Brackish Water Lens
KP1	587	-136	3.4	139
KP2	575	-81	2.0	83
KP3	525	-131	3.3	134
KP4	528	-145	3.6	148
KP5	525	-78	1.9	80
KP6	262	*	*	*

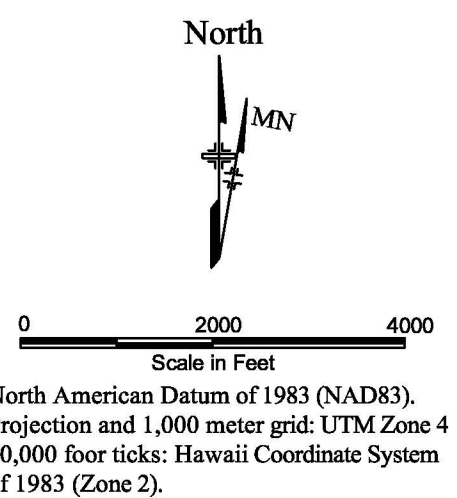
*Because Sounding KP6 was determined to be distorted by cultural interferences (i.e. pipeline, etc.) there is no calculation for this sounding.



 BLACKHAWK A DIVISION OF ZAPATAENGINEERING		Kawela Plantation Homeowners Association <i>Island of Molokai</i>			Geoelectric Cross-Section From 1-D TDEM Inversions Kawela Transect A-A' <i>Kawela Plantation Maui Co., Island of Molokai</i>		
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- Explanation**
- + ¹ TDEM Loop Location
 - A - - - A' Geoelectric Cross-Section
 - 1 (3.5) Water Well, Static Water Level (Ft.)
 - WT1 Water Tank
 - + Sounding in Which Groundwater is Expected in Basal Mode.
 - 145 Approximate Elevation of Top of Seawater Interface in Feet.



**Kawela Plantation
Homeowners Association
Island of Molokai**

**Interpretation Summary Map
Kawela Plantation
Maui County, Island of Molokai**

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5017

Date:
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Drawn By:
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Scale:
1" = 2000'

Figure:
5-2

6.0 CONCLUSIONS AND RECOMMENDATIONS

The main objective of the TDEM surveys on the Kawela Plantation Homeowners Association Property located on the Island of Molokai was to explore for basal groundwater resources. The optimum locations for groundwater in the basal mode are expected to occur where the thickest lens of fresh-brackish water is detected floating on seawater.

The results from the TDEM soundings collected at the approximate 525 ft (160 m) elevation above the town of Kawela shows that beneath all of the study areas are interpreted to contain basal mode groundwater (reference Figure 5-1). The area with the thickest interpreted groundwater lens is located beneath Sounding KP4 (148 ft), which is located approximately 1,000 ft east of the East Kawela Stream Gulch. This area of the property is likely gaining the most influx of groundwater recharge from both the East and West Kawela stream drainages and that is why the results from Soundings KP3 and KP4 show the thickest groundwater lens of these areas (reference Table 5-1). The Kawela Wells 1, 2 and 3 each have a reported head of 3.5 ft and the data from Sounding KP4 shows good comparison to this value with an interpreted head of 3.6 ft. Therefore, within the vicinity of Soundings KP1, KP3 and KP4 the potential for fresh-brackish groundwater lens appears to be the greatest.

The interpreted thinning of the fresh-brackish water lens beneath Soundings KP2 (81 ft) and KP5 (78 ft) may be related to their location away from Kawela Stream Gulch and there may be less groundwater recharge in this area.

Additional TDEM soundings located both above and below existing data sets may help define the extent of the basal mode lens and potential high-level groundwater in this portion of the Island of Molokai.

7.0 CERTIFICATION

All geophysical data analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by Blackhawk, a Division of ZAPATA ENGINEERING, Senior Geophysicists.

This geophysical investigation was conducted using sound scientific principles and state-of-the-art technology. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing, interpretation, and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review.

A geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances.